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Balancing Emergency Message Dissemination and Network Lifetime in Wireless Body Area Network using Ant Colony Optimization and Bayesian Game Formulation

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Abstract

Nowadays, Wireless Body Area Network (WBAN) is emerging very fast and so many new methods and algorithms are coming up for finding the optimal path for disseminating emergency messages. Ant Colony Optimization (ACO) is one of the cultural algorithms for solving many hard problems such as Travelling Salesman Problem (TSP). ACO is a natural behavior of ants, which work stochastically with the help of pheromone trails deposited in the shortest route to find their food. This optimization procedure involves adapting, positive feedback and inherent parallelism. Each ant will deposit certain amount of pheromone in the tour construction it makes searching for food. This type of communication is known as stigmetric communication. In addition, if a dense WBAN environment prevails, such as hospital, i.e. in the environment of overlapping WBAN, game formulation was introduced for analyzing the mixed strategy behavior of WBAN. In this paper, the ant colony optimization approach to the travelling salesman problem was applied to the WBAN to determine the shortest route for sending emergency message to the doctor via sensor nodes; and also a static Bayesian game formulation with mixed strategy was analyzed to enhance the network lifetime. Whenever the patient needs any critical care or any other medical issue arises, emergency messages will be created by the WBAN and sent to the doctor's destination. All the modes of communication were realized in a simulation environment using OMNet++. The authors investigated a balanced model of emergency message dissemination and network lifetime in WBAN using ACO and Bayesian game formulation.

***Keywords*:** Wireless Body Area Network; Ant Colony Optimization; Bayesian Game Model; Sensor Network; Message Latency; Network Lifetime

1. INTRODUCTION

With the development of cellular networks, the internet of things has reached the pinnacle of glory in our day-to-day life. Wireless sensor networks help in connecting everything i.e. devices, systems, machines and humans. WBAN is a specific wireless sensor network which is applied in health care for diagnosis as explained in [1-3].

INSERT TABLE 1

WBAN usually have a number of sensor nodes in the body or even implanted inside the human body, which are capable of measuring parameters like ECG, heartbeat, temperature, blood glucose level, etc. Many technological advancements are coming up related to WBAN in many literatures for finding the shortest route for sending emergency information. In that way, an enhanced Ant Colony Optimization (ACO) approach for disseminating emergency messages has been proposed. The strategies of WBAN communication between the patient (source) and the doctor (destination) are depicted in Table 1. The Zigbee mode of communication helps in transmitting the data from one station to the next extend up to about 70 metres, although very much greater distances may be reached by relaying data from one node to the next in a network. The local host can be used to communicate on the internet. The LoRaWAN is predominantly used for long distance communication. There will be central coordinator called as a gateway/hub which collects all the available information from the sensors and sends to the server of caregiver network. The care-givers'/doctors analyse the medical information and gives e-prescription to the patients accordingly.

Fig. 1 shows the workflow of wireless body area network, in which the patient has some sensor nodes for collecting information regarding his blood pressure, heartbeat, glucose level, etc., which are all sent to the sensor hub, which in turn sends to the cloud server through the mobile gateway. The doctor and the ambulance are intimated if any serious issue prevails.

INSERT FIG. 1

2. RELATED WORK

This section deals with the survey of some of the ant colony algorithms and game theoretic approaches related to WBAN.

Usually in colonies of ant there is no central control for anything. At society, there is a visibility of behaviour of ants. Their interesting behaviour has made us to do new algorithms. In every field these algorithms play its role. Ant colony optimization is one among the popular algorithm. This framework's agents are ants and it uses memory and decisions for pheromone updating. ACO gives the best result when compared with other state-of-art algorithms. ACO can be called as search strategy since it updates pheromones for finding solutions. So every ant is responsible for making independent decisions for a solution in optimization using local steps. So the ants will search every second. Then outcomes will be evaluated and updated.

The most basic mechanism of colony of ants finding a shortest path in search of food is shown in the book of [4]. It clearly explains the fact how ants can communicate through pheromone trails. The heuristic of ACO depends on the choice of nearest node and pheromone of ACO depends on choice of past experience of ant colony for building better cycles. Every ant constructs a combination with respect to probabilistic transition rule. In the book [5], ACO is applied to minimize the effort it needs for testing anomaly detection. A hybrid nodal ACO is employed for getting preventive contingency for wind power also uses ACO. The ant colony System in the book [6], explains the search experience, pheromone deposition to get best route and the arc (i, j) for moving from one city i to another city j, removal of some pheromone to increase the selection for choosing alternative paths. ACO for vehicle routing problems are also depicted. ACO is finding the optimal path using pheromone deposition which solve many complex problems are given in [7]. In the Ph.D. thesis [8], a new decision making concept for improving the overall optimization behaviour using cognitive ACO is explained. AntNet, an approach for the adaptive routing learning tables for communication networks for solving optimization problems is explained in [9]. In the book [10], AntNet-FA, AntNet+SELA, AntHocNet, Ant Colony Routing are depicted clearly for routing in networks.

WBAN consists of sensors for monitoring ECG, heartbeat, blood pressure for patient, accelerometer for finding the location of monitoring patient, and communication for transmitting the sensed information to doctor. WBAN is commonly utilized for medical care where many patients are monitored continuously as depicted in [11]. There must be sensor nodes for transferring data through a wireless link. The protocols and technologies for WBAN issues for medical purposes in the networking area were elaborated in [12]. Recently, some game theory approaches were proposed for WBAN. The existence with uniqueness of Nash Equilibrium in the game was proved in [13]. Evolutionary game theory was proposed in [14]. A Bayesian based approach for controlling power is depicted in [15]. Contention delay is analysed as a game theoretic approach [16]. Meharouech et al. [17] depicted the game theoretic approach for a dynamic system for utilizing different transmission technologies. Liu and Wu [18] gave the analysis for cooperative game approach for interference avoidance in WBAN. Qiu et al. [19] discussed the Game theoretic framework for n-player game in WBAN coexistence. The features of ACO are utilized for sending emergency messages through the shortest path between the WBAN nodes. The ACO approach gives the routing information for on-demand path setup if the source and destination nodes are known for sending the emergency messages [20]. Ducatelle et al. [21] investigated ant-like mobile agent's algorithm for sampling full paths between source and destination nodes in a Monte Carlo fashion to find the shortest route for sending emergency messages. Gharehshiran and Krishnamurthy [22] adopted the Bayesian framework for the optimal network lifetime and number of measurements for each node is obtained through the network. Cooperative-game-based actor-to-actor coordination is used for increasing the network lifetime in the network [23].

3. EMERGENCY MESSAGE DISSEMINATION APPROACHES

This section deals with the soft computing strategies which are used for analysing to find optimal path for disseminating emergency messages.

3.1 Ant Colony Optimization

Each ant at regular interval of time, searches the destination node in a shortest route through the pheromone update. The pheromone update is used for routing the emergency messages through the nodes of shortest distance from WBAN nodes to the doctor's destination. The sensor nodes pass the information to the gateway, through which the doctor receives the emergency messages via the shortest path from the sensor nodes. The ants keep in memory about their paths and obstacles. There will be nodes visited list and traveling time when moving from one node to another. Like this a stochastic policy is maintained for taking decisions. The pheromone values are got through continuous learning of ants which depends on both current as well as past status of WBAN nodes.

This section clearly gives an overview of ACO technique. Ant colony optimization came into being because of the natural behaviour of choosing the shortest path for ants in finding its food. The shortest path reinforced in the behaviour of ants for finding food is given by Equation (1).

$$Shortest\ path = \frac{n\_ants\frac{Pheromone}{x-distance}}{\frac{Shortest\ distance}{Time}} \quad (1)$$

This shortest path is achieved and communicated to other ants by means of their in-built stigmergic behaviour of ants. So ACO algorithms are autocatalytic positive feedback algorithms. In travelling salesman problem, each ant act as a simple agent which chooses the city with a probability which is a function of distance of town and the amount of pheromone at each edge. It is important to note that the already visited town should not be visited again. The fitness function is denoted by d_{ij} as given in Equation (2).

$$d_{ij} = \sqrt{(x_i - x_j)^2 + (y_i - y_j)^2} \quad (2)$$

The pheromone deposited on edge (i, j) at time t is given by $\tau_{ij}(t)$. In each cycle, the pheromone intensity is updated by $\frac{Q}{L_k}$. Because of this factor only shortest path is achieved. The summation of newly deposited pheromone is given by $\Delta\ \tau_{ij}$. The pheromone is updated using Equation (3).

$$\tau_{ij}(t+n) = p * \tau_{ij}(t) + \Delta\tau_{ij} \quad (3)$$

where p is the rate of pheromone decay per unit time and $\Delta\tau_{ij} = \sum\sum_{k=l}^{m} \Delta\tau_{ij}$.

The factors which derive transition probabilistic model are $i)\ \eta_{ij}\ and\ ii)\ \tau_{ij}$ which are given by Equation (3) and Equation (4) respectively.

$$\eta_{ij} = \frac{1}{d_{ij}} \tag{4}$$

When pheromone is updated, the next iteration will start by changing the ant path at the same time. Their weights are controlled by α and β. The probabilistic transition function is given by Equation (5),

$$P_{ij}^{k}(t) = \left\{\left[\tau_{ij}\right]^{\alpha}\left[\eta_{ij}\right]^{\beta} / \sum_{k \in allowed\ k}\left[\tau_{ij}\right]^{\alpha}\left[\eta_{ij}\right]^{\beta}, if\ k\ \in allowed_k\right\} \tag{5}$$

If α is nearly 1, the ants will collectively learn and hence there is somewhat delay in the path. If α is nearly 0, then there is a proper balance between τ and l, and delay is reduced. Since there is an adaptive way of finding the route, there should not be any loops to avoid latency. If the ant visit a node that is already visited then that information from ant's memory is deleted. The above probabilistic transition equation can be turned as ant colony system if α is dropped, for balancing between exploration and exploitation which is given by Equation (6).

$$S = \begin{cases} \arg\ max\{[\tau(r,u)].[\eta(r,u)]^{\beta}\}, if\ q\ \leq q_0 & i.e\ exploitation \\ S\quad , otherwise & i.e\ biased\ exploration \end{cases} \tag{6}$$

where

$u\ \in J_k(r)$,

$q_0 = Constant$,

$q - random\ variable$ &

$S - Outcome\ of\ probabilistic\ transition\ function$

The pheromone is updated locally using the rule given in Equation (7).

$$\tau(r,s) \leftarrow (1-\rho).\tau(r,s) + \rho \vartriangle \tau(r,s) \tag{7}$$

where τ= predetermined or calculated constant & edge (r,s) is updated after each ant search. The ant which reaches destination retrace its path. The pheromone table is updated by incrementing the probability of choosing its neighbour ant. WBAN nodes first collect data for the update of pheromone. Then only tunes other parameters for stochastic decision. The WBAN node learns the decision policy through pheromone updates. So the nodes singly and as colony will learn the pheromone and act adaptively for finding the shortest route. In this study, ten nodes are considered in WBAN.

The factor of fitness value is increased in the proposed method to reduce the time taken for sending the emergency messages. Whenever the patient needs any critical care or any other medical issue arises, emergency messages will be created by the WBAN and sent to the doctor's destination. The optimal shortest path was arrived using ACO for sending the emergency messages to the doctor for immediate medication as well as the lifetime of the network was decreased or increased according to Bayesian game formulation.

3.2 Bayesian Nash Equilibrium

This section discusses the Bayesian Nash Equilibrium with a special case on mixed strategies. Bayesian Nash equilibrium gives a plan of action for each player as a function of types that maximize each type's expected utility, i.e. expecting over the actions and types of other players.

Given a Bayesian game (N, A, Θ, P, U) with finite sets of players, actions and types, strategies with mixed strategy: s_i: Θ_i -→ Pi (A_i) which is a choice of a mixed action for player I as a function of his or her type. $s_i(a_i |\Theta_i)$ gives the probability under mixed strategy s_i that agent I plays action a_i, given that i´s type is Θ_i .

The interim expected utility is given by Equation (8)

$$EU_i(S|\Theta_i) = \sum_{\Theta_{-i} \in \Theta_i} p(\Theta_i|\Theta_{-i}) \sum_{a \in A} (\prod_{j \in N} S_j(a_j|\Theta_j) U_j(a, \Theta_i, \Theta_{-i}) \qquad (8)$$

Let us assume that the two players are Network 1 and Network 2; the actions are throughput and delay; and the types of network are set to increased network lifetime (I) and decreased network lifetime (D). Table 2(a) and 2(b) show the comparison of throughput and delay in networks having increased lifetime and decreased lifetime respectively.

INSERT TABLE 2(a) and 2(b)

INSERT TABLE 3(a) and 3(b)

Table 3(a) and 3(b) show the comparison of payoff for networks having increased lifetime and decreased lifetime respectively. Therefore, the mixed strategy Bayesian Nash equilibrium is (Mixture of Network 1 (2/3, 1/3), Mixture of Network 2 of type I (2/3, 1/3), Mixture of Network 2 of type D (0, 1)). Another mixed strategy Bayesian Nash equilibrium obtained is (Mixture of Network 1 (1/3, 2/3), Mixture of Network 2 of type I (0, 1), Mixture of Network 2 of type D (2/3, 1/3)).

4. RESULTS AND DISCUSSION

This chapter presents the results obtained for emergency message dissemination through Ant Colony Optimization and increased network lifetime through Bayesian game formulation. The data dissemination model uses all possible wireless network technologies that can be used for making communication between the patient and the doctor. There is no specific reason for choosing the number of nodes to be ten. The topology was chosen in random nature which does not affect the performance of the algorithm. The coordinates of chosen ten WBAN nodes are shown in Table 4. Then with the help of WBAN nodes the distance of all nodes are calculated. From the calculated distance, the node which has the shortest distance, can communicate the emergency message from patient to doctor. This is done using roulette wheel selection method. Then the fitness is calculated with the help of nodes in the WBAN and distances from each node. Then the pheromone of each ant is calculated. Finally the best solution, fitness and the total time are calculated. Through Bayesian game formulation, the networks are analysed for both increased as well as decreased network lifetime and the mixed strategies in both cases are tabulated.

INSERT TABLE 4

Using Matlab, the ant colony optimization algorithm is implemented for WBAN nodes, which chooses the shortest path and sends the emergency messages which will reach the doctor without any delay. The fitness value if increased, the best fitness will also increase; if fitness value is decreased, the best fitness also decreases which shows that there is a linear relationship. In contrast, the factor of x, if increased in fitness value, there is a decrease in best fitness value.

INSERT FIG. 2

The shortest route is found out for ant colony optimization using biograph viewer in Matlab tool. The shortest distance is found be 169.83 metres and the computational time for finding the shortest route is 1.5011 seconds. The mean and optimal solutions obtained from ACO algorithm is shown in Fig. 2. The initial conditions for the path for message dissemination were assumed that the source node is 10 and the destination node is 2 (Fig. 3). Fig. 4 shows the optimal path found from ACO algorithm for disseminating emergency message from Node 10 to Node 2.

INSERT FIG. 3

INSERT FIG. 4

From Fig.4, the source node and destination node are same but the time taken for reaching is only 18seconds (10+7+1), which is less than the initial ACO model of 20seconds (2+8+10). The enhanced ACO curve specifies the enhanced ACO technique which takes lesser time to reach the required destination whereas the ACO curve specifies ACO which takes more time to reach the destination.

INSERT FIG. 5

All modes of communication given in Table 1 have been realized in simulation environment using OMNeT++ 4.4. Fig.5 shows the ten nodes of WBAN connected in the distributed network and the realization of all modes of communication between the source and destination. The distributed network is the network where the sensors are connected to the doctor through the gateway. Source node senses the message created on emergency condition and optimizes the shortest route for disseminating emergency message to the doctor's destination point.

5. CONCLUSION

In this paper, the optimal shortest path for WBAN was determined using ant colony optimization algorithm. Bayesian game formulation was used for overlapped WBAN to find whether the network lifetime is increased or decreased with their Nash equilibria. The proposed method of balancing the emergency message dissemination and enhancing the network lifetime would serve as a tool for remote diagnosis and treatment of a patient by means of telecommunication technology. The extension of this study would concentrate on developing the WBAN Cloud services in an open source platform. The performance metrics can be explored and enhanced for medical emergency real-time services with increased longevity of the network lifetime.

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Fig.1.Workflow of wireless body area network.

Fig. 2. Mean and optimal solutions obtained for the fitness function d_{ij} over different iteration process using Ant Colony Optimization algorithm.

Fig. 3. Initial conditions for the path for message dissemination assuming the source node be 10 and the destination node be 2.

Fig. 4. Optimal path found from the Ant Colony Optimization algorithm for disseminating emergency message from Node 10 to Node 2.

Fig. 5. Realization of communication strategies using OMNeT++.

Table 1. Strategies of WBAN communication between the patient (source) and the doctor (destination).

Location of Patient	**WBAN Communication Strategy**
Patient at hospital	Mode of communication using ZigBee
Patient at home	Mode of communication using Local Host
Road accident cases	Mode of communication using LoRaWAN

Table 2. Comparison of throughput and delay in Network 1 and Network 2. (a) Increased network lifetime with probability, P (I) = 0.5 and (b) Decreased network lifetime with probability, P (D) = 0.5.

		Network 2	
		Throughput (bps)	**Delay (s)**
Network 1	**Throughput(bps)**	5 10	0 0
	Delay (s)	0 0	10 5

(a)

		Network 2	
		Throughput (bps)	**Delay (s)**
Network 1	**Throughput(bps)**	0 10	10 0
	Delay (s)	5 0	0 5

(b)

Table 3. Payoff for Network 1 and Network 2. (a) Increased network lifetime (I) and (b) Decreased network lifetime (D).

		Payoff		Payoff	Mixed Strategy
Network 1(I)	Throughput	5p	Delay	10(1-p)	p=2/3, 1-p = 1/3
Network 2	Throughput	5/3	Delay	20/3	q_2 = 0, 1-q_2 = 1
Network 1	Throughput	5q_1	Delay	-5/2q_1	q_1 = 2/3, 1-q_1 =1/3

(a)

		Payoff		Payoff	Mixed Strategy
Network 1(D)	Throughput	5(1-p)	Delay	10p	p=1/3, 1-p = 2/3
Network 2	Throughput	5/3	Delay	20/3	q_1 = 0, 1-q_1 = 1
Network 1	Throughput	5q_2	Delay	10-5q_2	q_2= 2/3, 1-q_2 =1/3

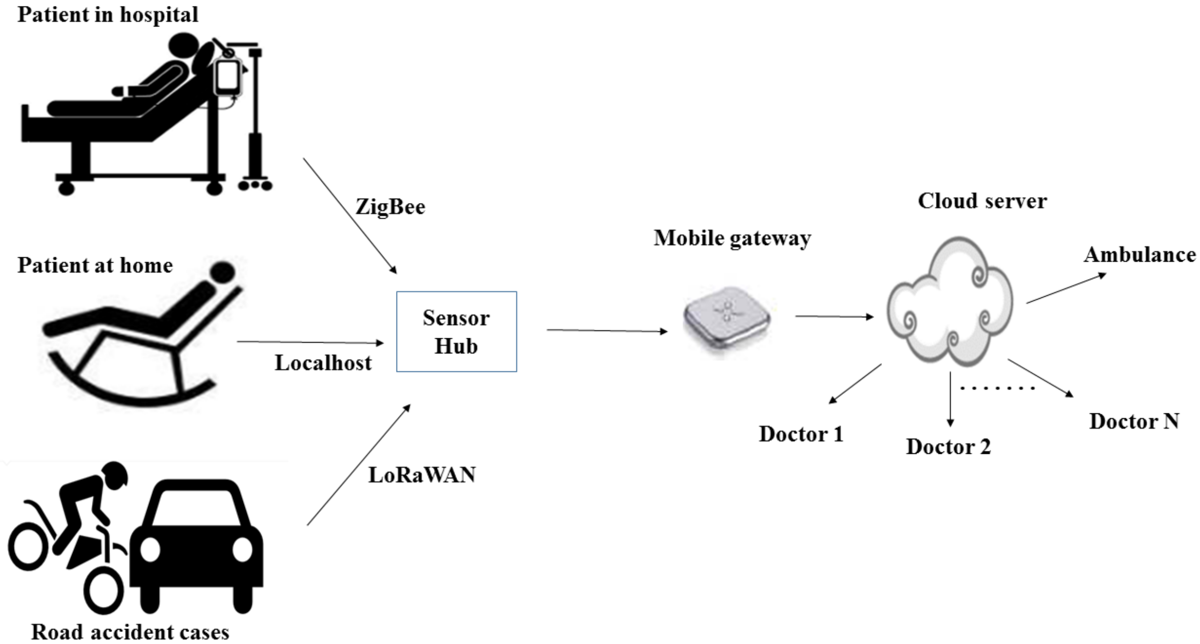
(b)

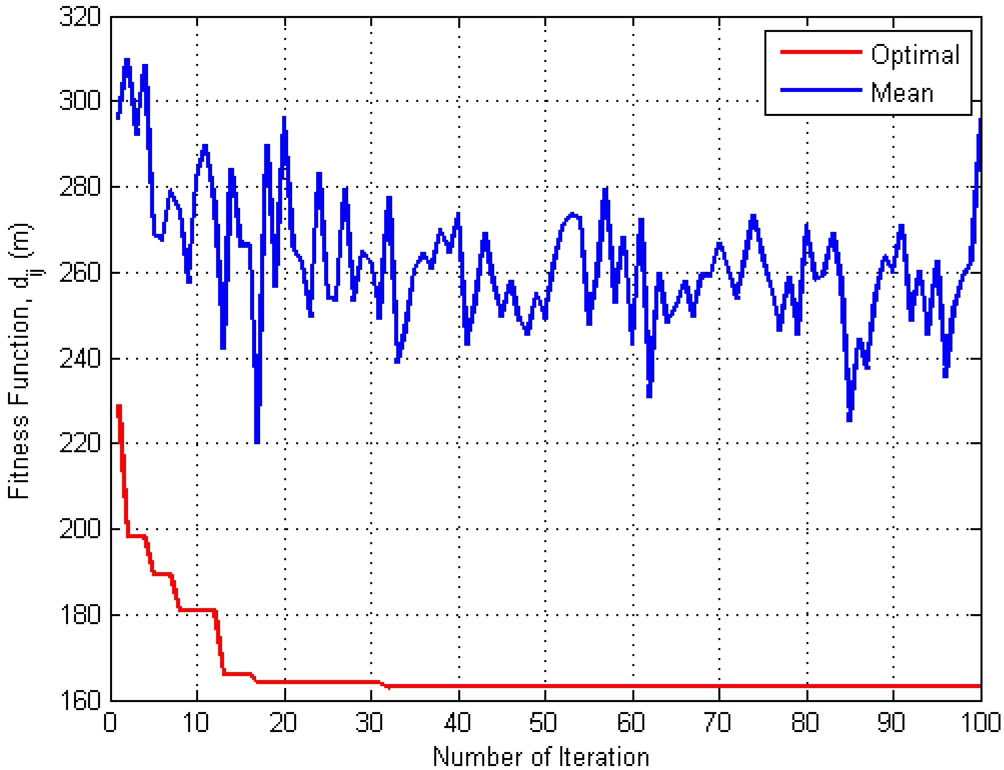
Table 4. Coordinates of the nodes in wireless body area network.

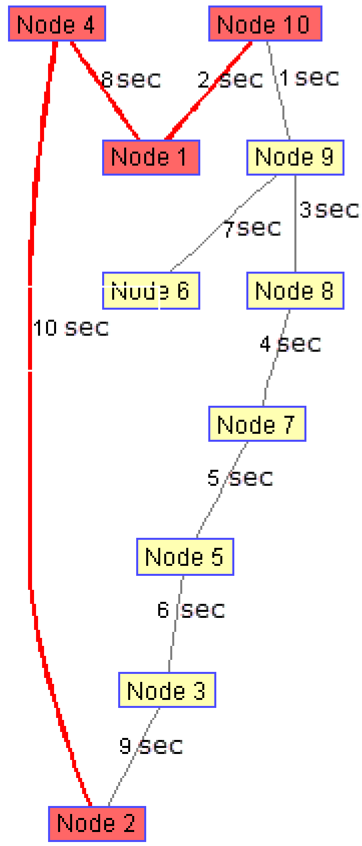
Nodes	X (m)	Y (m)
Node 1	23	26
Node 2	33	36
Node 3	45	46
Node 4	49	50
Node 5	55	56
Node 6	65	66
Node 7	79	80
Node 8	90	91
Node 9	99	100
Node 10	101	102

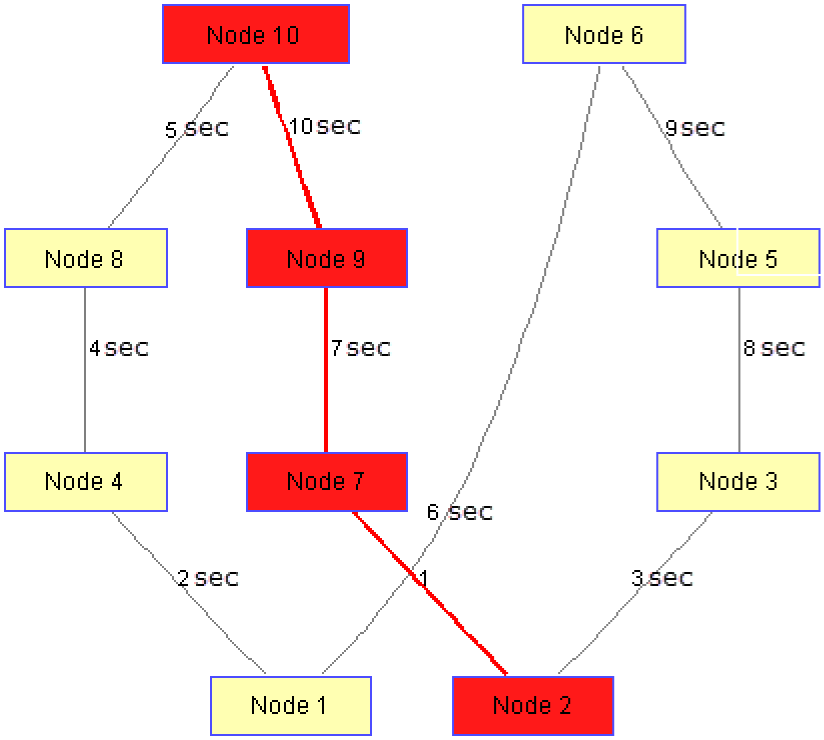
Highlights

- Achieved a fast and reliable emergency message dissemination using Ant Colony Optimization approach.
- Enhancement of network lifetime strategies was formulated using Bayesian game model and hence proved.

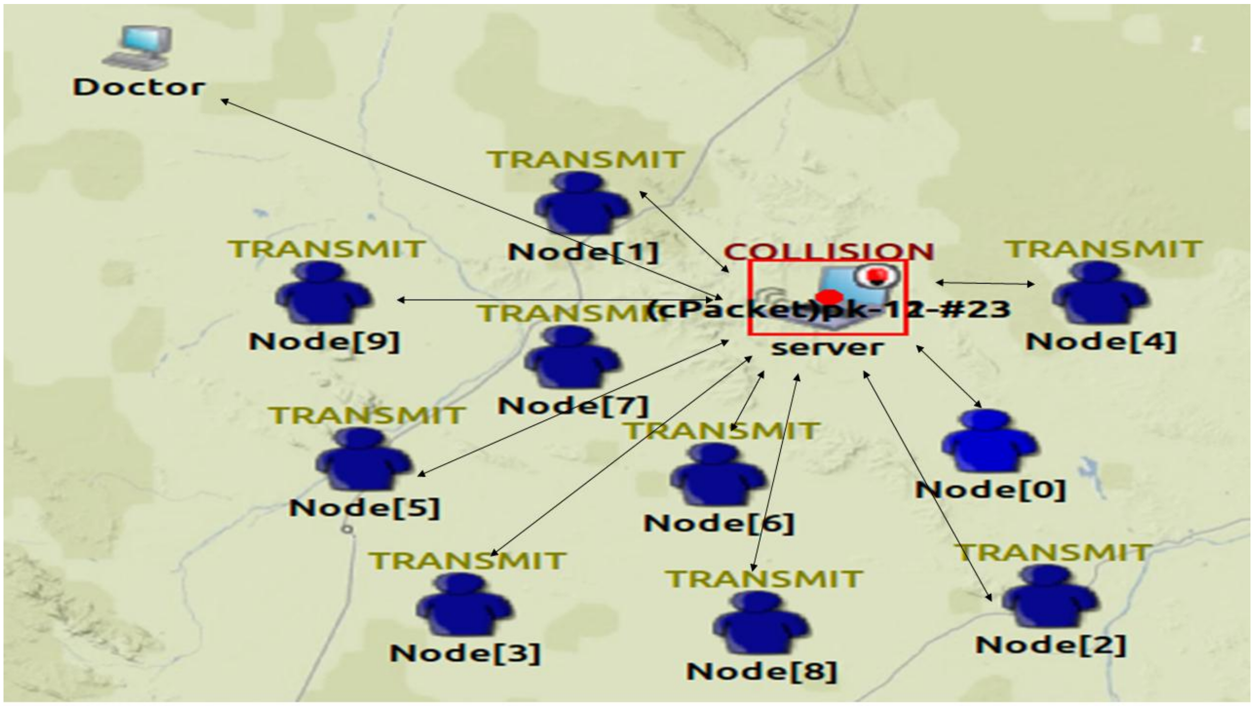

Patient in hospital
Patient at home
Road accident cases
ZigBee
Localhost
LoRaWAN
Sensor Hub
Mobile gateway
Cloud server
Ambulance
Doctor 1
Doctor 2
Doctor N


Optimal
Mean
Fitness Function, d_{ij} (m)
Number of Iteration
320
300
280
260
240
220
200
180
160
0
10
20
30
40
50
60
70
80
90
100


Node 4
Node 10
8sec
2 sec
1 sec
Node 1
Node 9
3sec
7sec
Node 6
Node 8
10 sec
4 sec
Node 7
5 sec
Node 5
6 sec
Node 3
9 sec
Node 2



Node 10
Node 6
5 sec
10 sec
9 sec
Node 8
Node 9
Node 5
4 sec
7 sec
8 sec
Node 4
Node 7
Node 3
6 sec
2 sec
1
3 sec
Node 1
Node 2


Doctor
TRANSMIT
Node[1]
COLLISION
TRANSMIT
TRANSMIT
Node[9]
(cPacket)pk-12-#23
Node[4]
server
Node[7]
TRANSMIT
TRANSMIT
Node[0]
Node[5]
Node[6]
TRANSMIT
TRANSMIT
TRANSMIT
Node[3]
Node[8]
Node[2]